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Materials for concrete

Concrete usually has to meet one or more of four functional requirements: strength, durability, fire protection and thermal insulation. The ability of concrete to meet specified requirements depends on the correct selection of materials as well as on good practice on site. There is a wide range of cements and aggregates from which to choose. This digest brings up to date the information about their main characteristics and the properties of concretes made from them. It does not include GRC which is dealt with in Digest 216, nor does it deal with reinforcing materials. It replaces Digest 150 which is now withdrawn.

Cements

Most concrete is made with ordinary or rapid-hardening Portland cement but there are other cements that will produce concretes with more specialised properties. The following notes amplify the information given in Table 1.

Ordinary Portland cement (OPC) (BS12) Develops strength sufficiently rapidly for most concrete work; as with all the other cements discussed, the rate of hardening is accelerated by warmth and retarded by cold. Its resistance to attack by sulphates is generally low.

Rapid-hardening Portland cement (BS12) Does not set any faster than ordinary Portland cement but after setting it develops strength more rapidly. Formwork can therefore be struck earlier and the cement is useful in cold weather.

Sulphate-resisting Portland cement (BS4027) Has a modified chemical composition compared with ordinary Portland cement to provide resistance to attack by sulphate solutions which are found in some soils. Its rate of heat evolution during hardening is low to medium. Sulphate-resistant cement with a low alkali content is available as an option in BS 4027 as described later under *Durability*. Such low-alkali cement will be beneficial in situations where an alkali-silica reaction may occur.

Ultra high early strength cement A very finely divided Portland cement with a higher proportion of gypsum than ordinary Portland cement but otherwise complying with BS12. The initial development of strength is much more rapid than that of ordinary or rapid-hardening Portland cements but there is little increase in strength after 28 days. The heat of hydration is greater at very early ages than that of rapid-hardening Portland cements. It is suitable for use in reinforced or prestressed concrete, but the creep of the concrete may be higher than that of concrete made with other Portland cements.

Low heat Portland cement (BS1370) Intended for use in large masses of concrete to reduce the temperature rise in the concrete and the possibility of subsequent cracking. It develops strength more slowly than ordinary Portland cement, particularly at low temperature. but its final strength is not lower. It usually offers better resistance to attack by sulphate waters than ordinary Portland cement. This cement is manufactured only to special order.

White Portland cement (BS12) Made by selection of the raw materials and by special manufacturing processes.

Coloured cements (BS12) Basically white or ordinary Portland cements to which between five and 10 per cent of pigment has been added, usually at the grinding stage. The pigment, being inert, dilutes the cement and the strength of the concrete will be slightly reduced; if necessary, this can be compensated by increasing the cement content of the mix by about 10 per cent.

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Portland-blastfurnace cement (BS146) Made by grinding a mixture of granulated blastfurnace slag and ordinary Portland cement clinker or mixing ground granulated blastfurnace slag and Portland cement. It is similar to ordinary Portland cement but its strength development is somewhat slower; it therefore requires longer curing periods, particularly in cold weather. Portland-blastfurnace cement is useful when concreting large masses because its slower rate of heat evolution helps to reduce the temperature rise in the concrete.

Low heat Portland-blastfurnace cement (BS4246) Similar to Portland-blastfurnace cement but with a higher slag content; intended for use in large masses and cement-rich thick sections of concrete to reduce temperature rise and subsequent cracking. It develops strength more slowly than ordinary Portland cement, particularly at low temperature. With slag contents in excess of about 70 per cent, it is more resistant to sulphate attack than Portland-blastfurnace cement and ordinary Portland cement.

Supersulphated cement (BS4248) Consists of granulated blastfurnace slag, calcium sulphate and a small amount of Portland cement. Its resistance to attack by sulphates over the range of concentrations commonly encountered in groundwaters is similar to that of sulphate-resisting Portland cement. Good quality concretes made with supersulphated cement have an acceptable life in mildly acid conditions. The cement requires extra care in storage to avoid deterioration, and the concrete should be kept moist continuously for several days after casting to reduce surface dusting.

High alumina cement (BS915) Differs in its manufacture, chemical composition and characteristics from Portland cements. It was developed originally for its ability to resist attack by sulphates. Concrete made with it develops very high early strength allowing it to be brought into early use, and this may be useful for temporary works. A substantial reduction in concrete strength may occur subsequently associated with 'chemical conversion'.[6] High alumina cement should not be used in structural concrete; its use is not covered by CP 110. High alumina cement is used in refractory concrete.

Cements containing pozzolanas These are factory-produced mixtures of a Portland cement and a natural or artificial pozzolanic material, such as pulverised-fuel ash, that combines with lime (eg lime released by the setting of the Portland cement) at ordinary temperatures in the presence of water to produce compounds with cementing properties. They have been little used so far in the UK but are used more widely on the Continent and in the USA. They are classified into:
Portland pozzolana cements which contain less than 20 per cent by mass of pozzolana and do not necessarily satisfy the BS 4550 test for pozzolanicity. These cements have properties broadly similar to ordinary Portland cements although at the higher levels of pozzolana they show some reduction in the rate of strength development, a lowered rate of heat evolution and an increased resistance to chemical attack.
Pozzalanic cements which contain up to 40 per cent by mass of pozzolana and which satisfy the BS 4550 test for pozzolanicity. Compared with OPC they have increased resistance to chemical attack and a lower rate of heat evolution which can be used to advantage in mass concrete. The rate of strength development is, however, reduced.

The use of different cements

From Table 1 and the above comments it can be seen that if a cement having a special property is required, then other properties of this cement may restrict its use. Heat of hydration, for example, is linked with the rate of strength development; if a high early strength is obtained the user must be aware that heat will be evolved quickly, and this may not always be desirable. When an unfamiliar type of cement is used for the first time, the user should ascertain how it differs from ordinary Portland cement and any special precautions that should be taken in its use. Neither supersulphated cement nor high alumina cement must be mixed with any other type of cement or with lime; all mixers, plant and tools must be thoroughly cleaned before and afer using these cements to avoid interaction with other types.

Additional materials with cementitious characteristics
Pulverised-fuel ash (pfa) A by-product of power station furnaces fired by pulverised coal. It can be used as a constituent of a Portland pozzalana or a pozzalanic cement or it can be added at the mixer with the cement and aggregate. For use in concrete, pulverised-fuel ashes have to be carefully selected and their properties, such as carbon content and grading, carefully controlled. The requirements are given in BS3892, but it may be useful to refer to the recommendations of the suppliers for specific applications.

When used in a Portland cement concrete, pulverised-fuel ash both acts as a pozzolana and modifies the overall grading of the mix. It is commonly used in mass concrete to reduce the heat of hydration by replacing a proportion of the cement. Typically, up to 30 per cent of the cement is replaced with pulverised-fuel ash although even higher percentages have been used in mass concrete. Replacement of cement by pfa leads to a reduction in early strength but, by pozzolanic action, this loss is generally recovered within six to 12 months. The predominantly spherical shape of the particles improves the workability and thus lowers the water demand of the concrete. By allowing for this and the changed overall grading in careful mix designs, it is possible to achieve the same concrete strength at early

ages in mixes containing considerable proportions of pfa as for the corresponding mixes without this addition. Cement/pfa mixes have proved useful in grouting and in concrete pumping. Pulverised-fuel ash improves the resistance of OPC concrete to sulphate attack provided that the ratio of pfa to OPC in the mix is between 1:4 and 1:2. At the higher addition levels, however, the rate of strength development may be adversely affected.

Ground granulated blastfurnace slag Can also be used in Portland cement concrete by incorporation at the mixer to replace a proportion of the cement. Replacement levels may be anything up to 90 per cent depending on the properties required of the concrete. Strength development at earlier ages is reduced particularly at higher replacement levels but this loss may be recovered within six to twelve months depending on the slag content. By careful mix design and utilisation of the better workability of slag-containing mixes, equivalent strength at earlier ages can be obtained. Ground granulated slag mixes have proved useful in grouting and concrete pumping and the resistance of ordinary Portland cement concrete to chemical attack may be improved, depending on the amount of slag incorporated; 70-90 per cent is recommended for sulphate resistance. Ground granulated blastfurnace slag mixes also have a lower rate of heat evolution that OPC concrete.

Aggregates

Aggregates make up the major part of the volume of concrete and their properties affect the characteristics of the concrete such as density, strength, durability, thermal conductivity and elastic, thermal, shrinkage and creep movements, as shown in Table 2. Aggregates should not be of a type, nor contain impurities that react adversely with the cement or embedded metal. The use of aggregates that have a high drying shrinkage is described in Digest 35. The shape and surface texture of the aggregate particles and their grading, ie the distribution of particle sizes, are important factors influencing the workability and strength of concrete.

It is convenient to classify aggregates as lightweight or dense, according to their bulk density. BS3797 defines lightweight aggregates as having a density less than 960 kg/m³ for coarse aggregate, or 1200 kg/m³ for fine aggregate.

Dense aggregates

Most aggregates fall into this category including natural aggregates such as sands, gravels, and crushed rock aggregates, complying with BS882 or BS1201. The main functional requirement of concrete made with dense aggregates is to provide strength and durability; the concrete may also be required to provide fire protection which will depend on the aggregate used as discussed later.

The grading of the fine aggregate (material passing a 5mm sieve) has a considerable influence on the properties of concrete. The grading of fine aggregates should comply with one of the four grading zones specified in BS882. Zone 1 is the most coarse material and zone 4 is the finest. Materials complying with any of the four zones are suitable for making concrete, but to obtain the best results the proportion of fine aggregate in the mix should be reduced as it becomes finer, ie moving from zone 1 towards zone 4. This principle is followed in the prescribed mixes given in CP 110 and BS5328.

Most natural sands for concrete fall into grading zones 2 and 3 and most crushed rock fines fall into grading zones 1 and 2.

Table 1 Properties of cements

Cement type	BS No	Rate of strength development	Rate of heat evolution	Resistance to sulphates
Main types of Portland cement				
Ordinary (opc)	12	medium	medium	low
Rapid-hardening	12	high	high	low
Sulphate-resisting	4027	low-medium	low-medium	high-very high
Other types of Portland cement				
Ultra high early strength	–	high-very high	high-very high	low
Low heat	1370	low	low	medium-high
White	12	Properties similar to those of ordinary Portland cement		
Coloured	12			
Cements containing blastfurnace slag				
Portland-blastfurnace	146	low-medium	low-medium	low-medium*
Low heat Portland-blastfurnace	4246	low	low	low-high*
Supersulphated	4248	medium	low	high-very high
Portland pozzolana cement	–	low-medium	low-medium	low-medium
Pozzolanic cement	–	low	low-medium	medium-high
High alumina cement	915	very high but will decline	very high	low if 'converted'

*Depending on slag content

Research on crushed rock aggregates[2] has shown that materials from different sources may require widely different water contents to produce concretes of the same workability. Such changes in water demand change the the water/cement ratio and hence the strength of the concrete. For example, for a range of 24 different aggregates, Fig 1 shows that 1:6 mixes of equal workability required free water contents from about 170 kg/m³ to 230 kg/m³, resulting in crushing strenths from about 30 N/mm² to 50 N/mm². The water demand of an aggregate cannot be related to any single characteristic measured by tests specified in BS 812 and probably depends on a combination of factors such as particle shape, surface texture and combined grading. It is known that similar ranges of water demand apply to sands and gravels from different sources.

Some aggregates may reduce durability by causing excessive shrinkage (Digest 35) or alkali-silica reaction; the corrosion of embedded steel may be accelerated by those containing high levels of chlorides. Marine aggregates are satisfactory provided that the relevant chloride limits for the concrete given in CP 110 are not exceeded.

Air-cooled blastfurnace slag coarse aggregate A by-product of the manufacture of pig iron. Concrete made with slag complying with BS1047 has properties similar to those of concrete made with natural aggregates complying with BS882; it also has good fire protection properties. It has been shown[3] that slags having densities slightly less than that specified in BS1047 are suitable for making concrete.

Crushed brick Should consist of clean crushed bricks, not brick rubble containing mortar and plaster. Bricks usually contain soluble sulphates and if to be used as aggregate the acid-soluble sulphate content should not exceed one per cent SO .This aggregate has good fire protection properties and can also be used for exposed aggregate surface finishes of a variety of colours.

Lightweight aggregates

The following types of lightweight aggregate are commonly available:

Foamed blastfurnace slag	BS877
Clinker	BS1165
Expanded clay, shale or slate Sintered pulverised-fuel ash Pumice Exfoliated vermiculite Expanded perlite	BS3797

Each material has its own characteristics of density, particle shape and surface texture. The grading of the fines generally differs from natural sands being rather coarse but containing a high proportion of very fine particles. A variety of concretes can be made, from lightweight blocks and screeds to structural concrete as indicated in Table 2. These aggregates and the properties of concretes made from them are described in Digest 123.

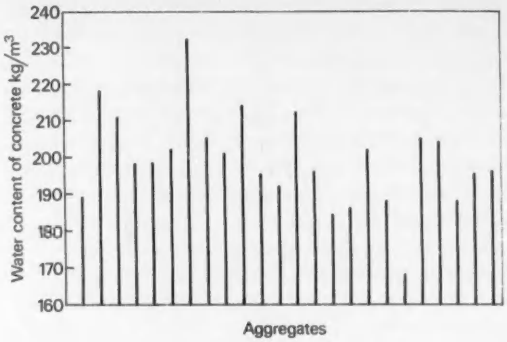

Fig 1 Water requirements of 24 mixes using different aggregates to produce concrete of the same workability

Water

Water should be clean and free from matter harmful to concrete in its fresh or hardened state. Advice is given in the Appendix of BS3148.

Admixtures

Admixtures are materials added in small quantities to the concrete batch, usually with the mixing water, to modify particular properties of the plastic or hardened concrete. Many proprietary admixtures are available, some containing several ingredients, and the materials involved range from simple inorganic salts to complex organic compounds or natural products. Although described by its principal function in modifying a concrete mix, an admixture may have secondary functions and may also affect other properties of concrete.

Preliminary site trials with the specific materials and conditions of the concrete work are generally needed to establish the appropriate mix proportions and to ensure that the admixture to be used provides the required performance without adverse secondary effects. The need for good concrete production practice is not decreased by the use of an admixture, and great care is required especially to control the correct dosage of admixture and to distribute it evenly throughout each batch of concrete.

Five types of admixture are defined in BS5075: Part 1, which gives acceptance test requirements covering admixture performance in concrete, and also includes tests for checking the uniformity of admixture composition.

Accelerating admixtures Accelerate the setting and early strength development of concrete and increase the rate of heat evolution. They are useful when working at low temperatures or when high early strength is required. Chloride-free salts, such as calcium formate, are available as accelerating admixtures. There is an increased risk of corrosion of any steel embedded in concrete containing chloride. Calcium chloride should not be used therefore as an accelerating admixture in reinforced or prestressed concrete. Limits on the quantity of chloride ion in different types of concrete as well as in admixtures are given in CP 110.

Retarding admixtures Reduce the rate of setting of concrete and are useful when working at high temperatures or when long ready-mixed concrete hauls are unavoidable. The dose necessary for a given retardation has to be increased at higher temperatures. Most retarders are based on organic hydroxy or phosphate salts.

Normal water-reducing admixtures (plasticising admixtures) Increase the workability of concrete at a given water/cement ratio. Alternatively, the water content can be reduced, typically by five to 10 per cent, to maintain the same workability and produce an increase in strength. These admixtures do not significantly affect the air content or the setting characteristic of concrete. They are generally based on salts of lignosulphonate or hydroxy carboxylic acids.

Accelerating water-reducing admixtures Combine the principal functions of an accelerating admixture and a water-reducing (plasticising) admixture.

Retarding water-reducing admixtures Combine the principal functions of a retarding admixture and a water-reducing (plasticising) admixture.
Other types of admixtures include air-entraining admixtures and super-plasticisers.

Air entraining admixtures Promote the formation and entrapping of very small air bubbles during mixing. The entrained air improves the workability and finishing qualities of the concrete and enhances its durability, particularly in relation to resistance to freezing and thawing actions under wet conditions and to treatment with de-icing chemicals. The entrained air reduces compressive strength, but the improved workability permits a reduction in the water/cement ratio which offsets some of the loss of strength. Most air entraining admixtures are based on wood resin derivatives or anionic surface-active agents.

Superplasticising admixtures These are an extension of normal plasticisers in that they can be added to concrete at relatively high doses to produce enhanced plasticising or water-reducing actions. They are used either to produce flowing concrete without segregation, or a water-reduced high strength concrete. Superplasticisers generally consist of sulphonated derivatives of melamine-formaldehyde or naphthalene-formaldehyde.

Concrete properties and choice of materials

When in its plastic state the concrete should be workable so that it can be placed and fully-compacted with the means available. Full compaction is essential for the concrete to be durable and to achieve its required

Table 2 Properties of concrete using different aggregates

Aggregate	Typical range of dry density		Compressive strength	Drying shrinkage	Thermal conductivity at 5% moisture content*	Main functional requirement
	Aggregate	Concrete				
	kg/m³	*kg/m³*	*N/mm²*	*per cent*	*W/m°C*	
Flint gravel or crushed rock	1350–1600	2200–2500	20–80	0.03–0.08	1.6 –2.2	Class 2 fire resistance; Strength and durability
Crushed limestone	1350–1600	2200–2400	20–80	0.03–0.04	1.6 –2.0	
Crushed brick	1100–1350	1700–2150	15–30	–	0.85–1.50	
Expanded clay, shale or slate and sintered pulverised fuel ash	300–1050	1350–1800	15–60	0.02–0.12	0.55–0.95	Class 1 fire resistance; Thermal insulation; Strength and durability
Foamed slag	500–950	1700–2100	15–60	0.04–0.10	0.85–1.40	
Expanded clay, shale or slate and sintered pulverised fuel ash	300–1050	700–1300	2–7	0.03–0.07	0.24–0.50	
Foamed slag	500–950	950–1500	2–7	0.03–0.07	0.30–0.65	
Pumice	500–900	650–1450	2–15	0.04–0.08	0.21–0.63	
Exfoliated vermiculite and expanded perlite	60–250	400–1100	0.5–7	0.20–0.35	0.15–0.39	
Clinker	700–1050	1050–1500	2–7	0.04–0.08	0.35–0.65	

*Calculated from CIBS Guide; if available, measured conductivities should be used in preference to these for calculating standard U-values

strength and other mechanical properties. When it has hardened, concrete has usually to meet one or more functional requirements: strength, durability, fire protection and thermal insulation. Both cements and aggregates are important in relation to strength and durability but fire protection and thermal insulation depend almost exclusively on the type of aggregate used. Most concrete should be durable under ordinary conditions of exposure but special precautions must be taken when it is exposed to aggressive conditions, such as various forms of chemical attack, frost and fire. In reinforced and prestressed concrete, the concrete must provide effective cover to prevent corrosion of the steel (see Digest 59).

There are circumstances when a special combination of types of cement and aggregate is required to produce concrete with special properties. Table 2 shows the characteristics of concrete made with different aggregates, arranged in functional groups.

Lightweight aggregate concrete As can be seen from Table 2, concretes having a wide range of properties can be produced. For a particular aggregate, the properties largely depend on the mix proportions used and on the degree of compaction obtained with a particular method of producing the concrete. More details about lightweight aggregate concrete are given in Digest 123; not all the lightweight aggregates suitable for thermal insulating concrete are suitable for structural lightweight concrete.

Structural lightweight concrete combines the advantage of a reduction in dead weight by about one-third, with improved thermal insulation and fire resistance, and adequate strength. Mixes richer than those usually associated with lightweight concrete are used and the mix proportions are selected to obtain a workable mix that can be fully compacted into a dense concrete so as to provide cover and bond to the reinforcing steel. The structural applications of lightweight aggregate concrete are discussed in Digest 111.

Strength and mechanical properties The strength of concrete is usually measured as a compressive strength but there are circumstances where other mechanical properties, eg transverse strength (indirect-tensile strength) or elastic modulus need consideration in terms of the materials used. As shown previously, the compressive strength of concrete depends on the source of the aggregate. Table 2 shows that lightweight aggregates are not suitable for very high strength concrete; it is often found easier to produce such concrete with crushed rock aggregates rather than with sand and gravel. Some admixtures, eg air-entraining agents, have a considerable effect on the strength of concrete.

There are conditions, as in road slabs, where the transverse or indirect-tensile strength of concrete is more important than its compressive strength. Concrete made with crushed rock aggregate tends to have a higher transverse strength than concrete of the same compressive strength made with sand and gravel; thus if a concrete is required for its transverse strength, a more economical mix may be possible if crushed rock aggregate is used.

The determination of the mx proportions using cements complying with BS12, BS4027 and uncrushed or crushed aggregates complying with BS882 for a concrete of specified strength and workability is described in Design of normal concrete mixes[4] This includes sections on the indirect-tensile strength and on air-entrained mixes.

Other mechanical properties of concrete, such as the modulus of elasticity and the creep characteristics, depend largely on the aggregates. CP 110 takes into account the reduced elastic modulus of lightweight aggregate concrete. Recent research has shown that the elastic modulus of concrete made with natural aggregates is dependent upon the characteristics of the aggregate.[5]

Durability

Protection of embedded steel against corrosion In reinforced and prestressed concrete, the embedded steel is protected against corrosion by the provision of an alkaline environment provided by an adequate thickness of dense, fully-compacted, good quality concrete, (See Digest 59). This protection is reduced if chlorides are present in the concrete either from admixtures or from aggregates, for example marine aggregates. Restrictions on the use of chlorides in admixtures, and limiting values of chloride content from all sources are given in CP 110.

Resistance to frost In the UK, concrete is seldom severely damaged by frost but the possibility cannot be entirely neglected unless the concrete is in a sheltered or dry position. To provide frost resistance in situations where concrete can become saturated with water, for example in kerbs, roads and bridges, the free water-cement ratio should be kept as low as possible and should not exceed 0.55. Particular care at early ages is required with cements having a slow strength development, or when additional materials, such as ground granulated blastfurnace slag or pfa, are used which may reduce the rate of strength development at low temperatures.

A high degree of frost-resistance can be obtained by the use of an air-entraining admixture and this is now specified for all concrete subject to the use of salt for de-icing. The air content should be from four to seven per cent by volume, according to the maximum size of the aggregates used.

The precautions to be taken on a building site during cold weather are given in Winter building[6]

Resistance to chemical attack A basic requirement for any concrete to withstand chemical attack is that it should have an adequate cement content, a low water/cement ratio, be thoroughly compacted and properly cured. Special cements or cementitious materials incorporated with ordinary Portland cement may increase the chemical resistance.[7] For concrete in sulphate-bearing soils and groundwaters see Digest 174, but specialist advice is required for sites contaminated with industrial waste. For cements required for corrosion-resistant floors see Digest 120.

Precautions against alkali-silica reaction Some aggregates containing particular varieties of silica may be susceptible to attack by alkalis (Na_2O and k_2O) originating from the cement or other sources, producing an expansive reaction which can cause cracking and disruption of concrete.[8] There are at present no British Standard tests for the reactivity of aggregates with alkalis. Damage to concrete from this reaction is likely only when all the following are present together:

a high moisture level in the concrete, approaching saturation;
a cement with high alkali content or other source of alkali;
aggregate containing an alkali reactive constituent.

Only a few failures from this cause have been identified in the UK and so where the service records of particular cement/aggregate combinations are well established no further precautions should be necessary. If, however, the materials are unfamiliar and precautions are judged to be necessary, these can take the following form:

measures to reduce the degree of saturation of the concrete, such as impermeable membranes;
use of a low alkali (less than 0.6 Na_2O equivalent) cement optionally available under BS 4027.

The use of cements containing pozzalanas or slags may also be effective in preventing excessive expansion but this should be established by appropriate tests or experience. This possible method of controlling alkali-silica reaction is still under investigation.

Concrete for fire protection
The behaviour of concrete when subjected to high temperatures, as developed in fires, is largely dependent on the type of aggregate used. Concretes made with siliceous aggregates have a tendency to spall whereas those containing limestone, blastfurnace slag and lightweight aggregates are virtually unaffected by spalling. Damage by spalling can be reduced by the incorporation of supplementary reinforcement in the concrete cover, but this is not necessary in the case of beams and columns made with limestone aggregate concrete. Limestone aggregate concretes also have a lower thermal conductivity and therefore provide better protection than an equal thickness of other dense concretes.

The accepted classification of aggregates in descending order of fire resistance of the concretes made from them is:

Class 1

(a) Non-spalling, good thermal insulation: Foamed slag and lightweight aggregates complying with BS3797.

(b) Non-spalling, reduced thermal insulation: Blastfurnace slag, crushed brick and burnt clay products,well-burnt clinker and limestone.

Class 2

Tendency to spall: Siliceous aggregates generally, eg flint gravel, and all natural crushed rock aggregates other than limestone.

Thermal insulation
To provide good thermal insulation, a concrete must have a low density. For a given density, the thermal insulation will vary depending on the aggregate used and on the amount of free water pressent (see Digest 108). Basically, an insulating concrete is one containing a large amount of air voids and this can be achieved by using lightweight aggregate concrete, aerated concrete, or no-fines (dense or lightweight aggregate) concrete.

No-fines concrete is usually made with aggregate between sizes 20 and 10 mm. It may be used for cast in situ load-bearing walls in single and multi-storey construction. Aerated concrete is described in Digest 178.

Documents referred to in the text

BRE Digests

35 Shrinkage of natural aggregates in concrete
59 Protection against corrosion of reinforcing steel in concrete
108 Standardised U-valves
111 Lightweight aggregate concretes - 3: Structural applications
120 Corrosion - resistant floors in industrial buildings
123 Lightweight aggregate concretes
174 Concrete in sulphate-bearing soils and groundwaters
178 Autoclaved aerated concrete

British Standards

BS 12:1978 Ordinary and rapid hardening Portland cement
BS 146:1973 Portland-blastfurnace cement
BS 812:1975 Methods of sampling and testing of mineral aggregates, sands and fillers
BS 877:1973 Foamed or expanded blastfurnace slag lightweight aggregate for concrete
BS 882,1201:1973 Aggregates from natural sources for concrete (including granolithic)
BS 915:1972 High alumina cement
BS 1047:1974 Air-cooled blastfurnace slag course aggregate for concrete
BS 1165:1966 Clinker aggregate for concrete
BS 1370:1979 Low heat Portland cement
BS 3148:1959 Tests for water for making concrete
BS 3797:1976 Lightweight aggregates for concrete
BS 3892:1965 Pulverised-fuel ash for use in concrete
BS 4027:1980 Sulphate-resisting Portland cement
BS 4246:1974 Low heat Portland-blastfurnace cement
BS 4248:1974 Supersulphated cement
BS 4550 Methods of testing cement Part 2:1970 Chemical tests
BS 5075:1974 Concrete admixtures. Accelerating admixtures, retarding admixtures and water-reducing admixtures.
BS 5328:1976 Methods for specifying concrete
BS CP 110 The structural use of concrete: Part 1:1972 Design, materials and workmanship

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3 The use of lighter-weight blastfurnace slag as dense coarse aggregate in concrete; W Gutt, D C Teychenne, and W H Harrison; BRE Current Paper CP93/74.
4 Design of normal concrete mixes; 1975; HMSO; London.
5 The estimationof the elastic modulus of concrete for the design of structures; D C Teychenne, L J Parrot and C D Pomeroy; BRE Current Paper CP23/78.
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7 Chemical resistance of concrete; W Gutt and W H Harrison; BRE Current Paper CP23/77.
8 Alkali aggregate reactions in concrete in the UK; W Gutt and P J Nixon; Concrete, Vol 13 No 5, May 1979.

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